

INDEX

A

Absorption, 43
coefficient, 44, 372
graph vs. wavelength, 373
indirect, 374
lattice, 145
Acceptance angle, fibers, 117
Acceptors in semiconductors, 189
Acousto-optic effect, 476
figure of merit and table, 481
Acousto-optic modulator, 477, 481
Bragg regime and diffraction, 479, 495
Raman–Nath regime, 477
Active Matrix Array, 417–418
Active pixel sensor, 418
Air mass, 426
Airy disk, 62
angular radius, 62
Airy, George, 58, 91
Airy rings, 58, 59, 61
Alloys, semiconductors
III-V alloys, 237, 257
III-V bandgap diagram, 155
III-V ternary alloys, 237
Amorphous structure broadening, 305
Amplified spontaneous emission (ASE), 285, 287
Amplifier, *see* Optical amplifier
Anisotropy, optical, 11, 446, 447
refractive index, 11, 445
table of crystals, 446
Antireflection coating (AR), 39–40, 365, 421
Argon-ion laser, 359
Attenuation, 43
coefficient, 43, 143
optical fibers and dB, 143–151
table for fibers, 147
vs. bend radius, 150
Avalanche, 387
breakdown voltage, 388
multiplication factor, 388
noise, 414
Avalanche photodiode (APD), 386
absorption region in APD, 393
guard ring, 388
internal gain, 388
noise, 414
photogeneration, 393
primary photocurrent, 388, 390
principle, 401
responsivity of InGaAs, 390
separate absorption
and multiplication (SAM), 393–395
grading and multiplication (SAGM), 393
Si reach-through, 386
silicon, 390
superlattice, 395

B

Bandgap, energy gap, 182
III-V bandgap diagram, 257
Bandwidth, 130
optical, electrical, 134–135
Bandwidth theorem, 49
Bardeen, John, 178
Bayer color image sensor, 417
Beam
circular cross-section, 176
diameter, 7
displacement, *see* Lateral displacement
of light
divergence, 8
Gaussian, 62–63, 289, 292
light, 6
self-focused, 496
splitter cube, 35
Becker, P. C., 276, 463
Bending losses, 148
Bennett, William Jr., 290
Biaxial crystals, 446
Birefringence, 445
calcite, 450
circular, 456
induced, 464
quartz, 453
Birefringent
circularly, media, 458
crystal, 445
optical devices, 452
prisms, 456
retarding plates, 452
Bit rate, 130, 135
capacity, 130
intersymbol interference, 131
nonreturn-to-zero (NRZ), 135
return-to-zero (RZ), 131
Black body radiation law, 271
Bloch wave in a crystal, 78, 195
Boundary conditions, electromagnetism, 26, 27
Bragg angle, 479
Bragg diffraction condition, 67, 260, 285, 495
Bragg fibers, 159–160
gratings and sensors, 163–167
Bragg reflector, 41
Bragg wavelength, 163, 339
Bragg, William Lawrence, 65, 67
Brewster angle, 29, 30
reflection and transmission, 37–38
Brewster, David, 29
Brewster window, 289, 303
Broadening
amorphous structure, 305
collision, 304
homogeneous, 304
inhomogeneous, 305
lifetime, 304

Broadening (*continued*)
 optical gain curve, 303
 pressure, 304
 Burrus device, 247

C

Calcite, 446, 450
 principal section, 450
 rhomb, 450
 specific rotary power, 457
 Carrier confinement, 315
 Cauchy equation and diamond, 14
 Cavity lifetime, 300–301, 337
 Centrosymmetric crystals, 463
 Charge-coupled device (CCD), 419–421
 Frame architecture, 420–421
 full frame architecture, 420–421
 Interline transfer architecture, 420–421
 sensor, 416

Chirp, chirping, 158, 496

Chromatic dispersion, 125–126

Cladding, 95
 attenuation, 102
 layers, 247

Coefficient of index grading, 137

Coherence
 length, 48
 mutual temporal, 50
 perfect, 47
 spatial, 47, 50
 temporal, 47
 time, 48

Collision broadening, 304

Compensation doping, 190

Complementary metal oxide semiconductor (CMOS)
 sensor, 416, 417

Complex propagation constant, 44

Complex refractive index, 45
 of InP, 46–47

Complex relative permittivity, 44

Conduction band (CB), 182, 196
 electron concentration, 188

Conductivity, semiconductors, 188

Confining layers, 238, 247

Conjugate image, 356

Constructive interference, 52

Coupled waveguides, 473

Coupling coefficient, 165

Cross-phase modulation, 158

Crystal momentum, 196

Current-Voltage Convention, 369–370

D

Degenerate semiconductor, 191
 Dense wavelength division multiplexing (DWDM), 156
 nonlinear effects, 157–159
 Density of states (DOS), 180
 effective, 185
 Depletion region (layer), 199, 365
 capacitance, 211, 380
 Depth of focus, 8

Destructive interference, 52
 Desurvire E., 276
 Detectivity, 411
 Dichroism, 451
 Dielectric mirrors, 40, 42, 344
 Diffraction, 58
 Fraunhofer, 58, 59
 Fresnel, 58
 diagram, 59
 order, 339
 pattern, 58
 circular aperture, 62
 rectangular aperture, 61
 single slit, 60
 principles, 58
 Diffraction grating, 64
 blazed (echelle), 67
 reflection, 65
 transmission, 65
 Diffraction grating equation, 65
 single slit, 61
 Diffusion (storage) capacitance, 214
 Diffusion current, 204
 Diffusion flux, 203
 Diffusion length, 203
 Diode equation, 208
 Diode ideality factor, 208
 Direct recombination, 215
 Dispersion, 125, 135
 bandwidth relations, 135
 chromatic, 140, 162
 coefficients, 140
 diagram, 104
 graph of ω vs. β , 106
 intermode, intermodal, 105, 110
 intramode, intramodal, 106
 material, 107, 119, 124, 171
 coefficient, 120
 graph vs. wavelength, 121
 modal, 104, 105
 polarization mode, 123
 profile, 123, 172
 profile-coefficient, 103
 relation, 12
 single mode fiber, 119
 table, 128
 total, 121, 125
 vs. wavelength, 121, 125, 127
 Dispersive medium, 16
 Distributed Bragg reflector, 165, 241, 338, 344
 Donors in semiconductors, 190
 Doppler broadened linewidth, 291, 293
 Doppler effect, 290
 Doppler shift, 480
 Double-heterostructure (DH), 226
 active layer, 315–316
 buried, 318
 contacting layer, 317
 device, 315
 Drift mobility, 188, 381
 Drift velocity, 255, 381–382
 graph vs. field, 382

E

EDFA, *see* Erbium doped fiber amplifier

Effective density of states, 185, 186

Effective mass, 183

Efficiency

detector, 375

fiber coupling efficiency, 261

He-Ne laser, 290

laser diode external power, 327

laser diode slope, 327

optical amplifier, 279

quantum efficiency, 327

external, 324, 376

external differential, 327

internal, 261, 328

Einstein coefficients, 270, 271

E vs. k diagrams, 194

direct bandgap, 196

indirect bandgap, 197

Electrical bandwidth of fibers, 130, 133, 253

Electromagnetic (EM) wave, *see* Wave

Electron affinity, 182

Electron ionization coefficient, 391–392

Electro-optic effects, 462

Kerr, 469

linear, Pockels, 463

Energy band, 179, 180

Energy band diagram, 180, 192, 367, 369

field applied, 192

GaAs laser, 361

heterojunction, 226, 317

pn junction, 220

Energy level, 179

long-lived, 277

Epitaxial growth, 238

Erbium doped fiber amplifier (EDFA), 276, 283

characteristics, efficiency and gain saturation, 280

energy diagram, 277

gain-flattened, 284–287

Excess carrier distribution, 215

External photocurrent, 370–372

time spread, 372

External quantum efficiency (EQE), 242

Extinction coefficient, 45

Extraction efficiency (EE), 243

Extraordinary wave, 447

Extrinsic semiconductors, *see* Semiconductors

F

Fabry, Charles, 53

Fabry–Perot interferometer, 68, 69

Fabry–Perot laser amplifier, 348

Fabry–Perot optical resonator, 54, 292

transmitted light, 56

Fall time, 253

Faraday effect (rotation), 483, 495

Faraday, Michael, 107

Fermi–Dirac function, 179, 181, 184, 228, 313

Fermi energy, 179, 187

Fermi level, 185, 186

Fiber, *see* Optical fibers

Fiber Bragg grating (FBG), 163

Fill factor (FF), 424; *see also* Solar cell

Finesse, 56

First Brillouin zone, 78

Flat-band voltage, *see* Reach-trough voltage

Four-level laser system, 269–270

Four photon mixing, 157

Franken, Peter A., 486

Franck–Condon principle, 249

Fraunhofer, Joseph, 59

Free carrier absorption, 255

Free spectral range, 54

Fresnel, Augustin Jean, 1

Fresnel prism, 492

Fresnel's equations, 26, 27, 88

Fresnel's optical indicatrix, 447

Full width at half maximum, *see* FWHM

Full width at half power, *see* FWHP

FWHM, 131

of a gas laser, 291

FWHP, 131

G

Gabor, Dennis, 354

Gain coefficient in Nd³⁺ doped glass fiber, 275

Gain saturation, 282

Gaussian beam, 21, 83, 292, 302

power and irradiance, 21

Gaussian broadening, 305

Gaussian dispersion, 134–135

Gaussian pulse, 133

Glan–Focault prism, 492

Glass preform, 154

Goos Haenchen phase shift, 88

Graded index fiber, 136–141; *see also* Optical fiber

dispersion and bit rate, 141

properties – table, 140

Graded index (GRIN) rod lens, 135, 139, 248

Group delay, 120

Group index, 14

graph vs. wavelength, 15

Group velocity, 15, 104, 114–115, 169

H

Half-wave plate retarder, 453

quartz, 453

Half-wave voltage, 466

Helical ray path, 108, 137

Helium–Neon laser, 287, 299, 301

characteristics – table, 358

efficiency, 290

energy diagram, 288, 358

modes, 291

principle of operation, 288

Herriott, Donald, 290

Heterojunction, 222

photodiodes, 393

phototransistor, 402

Heterostructure, 225, 226

device, 226, 245, 317, 321, 348

High (strong) injection, 214–216, 256

- Hole, 183
 diffusion current, 203
 diffusion length, 203
 ionization coefficient, 391
- Holey fiber, 160; *see also* Photonic crystal fiber
- Hologram, 354
- Holography, 354, 356
- Homogeneous broadening, 304
- Homojunction, 224, 313
- Huygens, Christiaan, 440
- Huygens-Fresnel principle, 59–60
- I**
- Image sensors, 415–421
 pixels, 415
- Impact-ionization, 387
- Index matching, 487
- Induced transition, *see* Stimulated emission
- InGaAsP on InP substrate, 319
- Inhomogeneous broadening, 305
- Injection, 201
 of excess minority carriers, 201
 pumping, 313
 strong, 215
 weak, 215
- Instantaneous irradiance (intensity), 19
- Integrated optics, 470
- Intensity of light, 21, 32
- Interference, 51
 incoherent, 73
- Interference fringes, 71
- Interferometers, 68–70
- Internal quantum efficiency (IQE), 242
- Intersymbol interference, 131
- Intrinsic concentration n_i , 186, 189
- Intrinsic semiconductors, *see* Semiconductors
- Irradiance, 18, 19
 reflected light, 32
- Isoelectronic impurities, 237
- Isotropic, 11
- J**
- Javan, Ali, 290
- Jones matrices, 490
- Jones units, 411
- Jones vector, 490
- K**
- Kao, Charles, 94
- Kerr coefficients – table, 469
- Kerr effect, 468–470
- Kerr effect modulator, 470
- Kerr, John, 462
- Kramers-Kronig relations, 46
- L**
- LASER, 265, 266–269; *see also* Laser diode
 active medium, 289
 active region, 312, 318
 amplifiers, 348
 distributed Bragg reflection (DBR), 338–339
 distributed feedback (DFB), 338, 339
 efficiency of the He-Ne, 290
- gain guided, 318
- gas, 287
 modes, 292
- He-Ne, 287, 299
 characteristics – table, 358
 efficiency, 290
 principle of operation, 288
- modes, 292, 294, 301, 302
- multiple quantum well (MQW), 322
- Nd³⁺:YAG laser, 269
- optical cavity, 268, 287, 297
- oscillation conditions, 295
- oscillator, 298
- output spectrum of a gas, 290
- output wavelength variations, 330
- principles, 266
- ruby laser, 267
- semiconductor, 348
- single frequency solid state, 338
 guiding layer, 339
- threshold gain, 296
- vertical cavity surface emitting (VCSE), 344
- Laser diode (LD)
 active region, 318
 buried heterostructure, 319
 characteristics, 324
 conversion efficiency, 328
 direct modulation of, 351–354
 distributed Bragg reflector (DBR), 338
 distributed feedback (DFB), 339
 divergence of output, 325
 double heterostructure, 332
 edge emitting, 318
 equation, 332
 external cavity, 342
 external power efficiency, 362
 Fabry–Perot, 318
 gain guided, 318
 heterostructure, 315
 homojunction, 315
 index guided, 319
 inversion layer, 312
 modes, 320
 modulation, 351
 principles, 311
 rate equations, 332
 single frequency, 338
 single mode, 319
 slope efficiency, 327
 stripe geometry, 317
 transient response, 352
 delay time, 353
 relaxation oscillation, 352
- tables, 329, 340
- threshold current, 314, 315
- transparency current, 314
- vertical cavity, surface emitting, 344
- Lasing emission, 267
- Lateral displacement of light, 25
- Lattice vibrations, 495
- LED, *see* light emitting diode, LED
- Lifetime broadening, 304
- Light absorption, 43

Light emitting diode, LED, 179, 224
 active region, 247
 AlGaAs, 256
 characteristics, 245–246
 cut-in voltage, 245
 edge emitting (ELED), 247–248, 261
 efficiencies and luminous flux, 242–244
 electronics, 251–253
 energy band diagram, 224
 external quantum efficiency (EQE), 242
 fiber coupling efficiency, 261
 for optical communications, 251
 heterojunction, 246
 high intensity, 233
 internal quantum efficiency (IQE), 242
 linewidth, 226, 229
 luminous efficacy, 244
 materials, 237–238
 optical fiber communications, 246–248
 output spectrum, 246
 phosphors and white, 249–251
 power conversion efficiency, 243
 principles, 224
 structure, 238–241
 superluminescent and resonant cavity, 350–351
 surface emitting (SLED), 247, 261
 turn-on voltage, 145
 wavelengths, 241
 white, 249

Lineshape function, 296

Linewidth, 124

Liquid crystal display (LCD), 458–462
 twisted nematic field effect, 459

Lithium niobate (LiNbO_3)
 acousto-optic, 476
 phase modulator, 471, 493
 Pockels effect, 463
 properties, 447

Load line, 424

Longitudinal axial modes, 302

Lorentzian lineshape, 304

Loss coefficient, 297

Luminescence, 249

Luminosity function, 243

Luminous
 efficacy of light source, 244
 flux, 243

M

Mach-Zehnder interferometer, 69
 Mach-Zehnder modulator, 70, 473
 Macrobending loss, 148
 Magneto-optic effects, 483
 Magneto-optic isolator, 495
 Magneto-optic modulator, 495
 Maiman, Theodore Harold, 363
 Majority carriers, 190
 Malus's law, 444
 Mass action law, 186
 Matrix emitter, 347
 Maximum acceptance angle, 117
 Maxwell's wave equation, 6, 10
 Mean thermal generation time, 210

Meinel and Meinel equation, 438
 Metalsemiconductor-metal (MSM) structure, 400
 photodiodes, 400
 Meridional ray, 108–109, 137
 Microbending loss, 148
 graph vs. bend radius, 150
 Microlaser, 347
 Midwinter, John, 34
 Mie scattering, 76
 Minority carriers, 190
 diffusion, 203
 diffusion length, 377
 Modal index, 163
Mode
 cavity, 55, 292, 314
 coherently coupled, 340
 field diameter (MFD), 112
 hop in lasers, 326
 intensity of transmitted, 57
 linearly polarized, 109
 number, 99, 292
 of propagation, 99
 resonator, 57
 TE, 100, 168–169, 303
 TM, 100, 168–169, 303
 transverse, 303
 Mode field diameter (MFD), 112–113
 Mode locking, 310–311
 Modulated directional coupler, 476
 Modulation of light, 441–497
 Monochromatic wave, 14
 MQW, *see* Multiple quantum well (MQW)
 Multimode fiber, 112
 Multiple interference, 61
 Multiple quantum well (MQW), 236, 322
 Multiple reflections
 in plates and incoherent waves, 73–74
 thin films, 70
 Multiplication region, 393
 Mutual temporal coherence, 51

N

Natural broadening, 304
 Negative absolute temperature, 272
 Net round-trip optical gain, 297
Noise
 current, 409
 equivalent power (NEP), 410
 NEP graph, 412
 excess avalanche, 437
 excess, 387
 noise figure, 286
 in an APD, 414
 in photodetectors, 408
 of an ideal photodetector, 412
 photon noise, 409
 quantum, 409, 413
 shot, 409
 Noncentrosymmetric crystals, 463
 Nondegenerate semiconductors, 191
 Nonlinear optics, 485
 Nonlinear effects, 157, 462, 486
 Non-thermal equilibrium, 272

- Normalized frequency, 100, 110
 Normalized index difference, 108, 110
 Normalized propagation constant, 114
 Normalized thickness, 100
 Numerical aperture, 117, 118, 138
- O**
- Optical activity, 456, 484
 dextrorotatory, 457
 levorotatory, 457
- Optical amplifier, 267
 erbium doped fiber amplifiers (EDFA), 276
 semiconductor optical amplifier, 348
 table, EDFA, 286
- Optical anisotropy, 445–446
- Optical bandwidth, 130, 134, 252
- Optical cavity, 272, 287
 intensity, 55
 maximum intensity, 55
 modes, 54
 in lasers, 301
 resonant frequencies, 54, 314
- Optical divergence, 7
- Optical confinement, 315
- Optical fiber, 95
 all wave fiber, 146
 attenuation, 142, 144
 cutoff wavelength, 111
 doubly clad, 127
 dispersion flattened, 127
 dispersion shifted, 122
 drawing, 152–155
 schematic, 152
 fundamental mode, 109
 graded index, 135–142
 light emitters, 246
 MAC number, 150
 manufacture, 152
 laydown stage, 153
 multimode, 111, 118, 170
 nonzero dispersion shifted, 127
 propagation constant, 114
 propagation of light, 109
 reduced slope, 126
 sensor, 166
 single mode, 111, 112, 115, 170
 single mode cutoff, 111
 step index, 107
 types of, 127
 V-number, 109
 zero dispersion shifted, 126
- Optical fiber amplifier, 276
 erbium ion doped, 276
 gain efficiency, 281
- Optical field, 4
- Optical frequencies, 11
- Optical gain, 267, 275, 291
 coefficient, 295–296
 lineshape, 291
 net round-trip, 297
 threshold, 297
- Optical indicatrix, 448
- Optical isolator, 484
- Optical laser amplifiers, 348
- Optical modulators
 coupled waveguide, 473
 integrated, 470
 intensity, 467
 Kerr effect, 470
 Mach-Zehnder, 473
 Pockels cell, 468
- Optical pumping, 267–268
- Optical resonator, 53
- Optical tunneling, 33, 34
- Optically isotropic, 11, 445
- Optic axis, 446
- Optimal profile index, 138
- Output power and photon lifetime in the cavity, 299–300
- Output spectrum
 LED, 226
 gas laser, 290
 laser diode, 315, 326–327
 white LED, 249
- Outside vapor deposition, 152, 153, 154
 schematic, 153
- P**
- Passive pixel sensor, 418
- Penetration depth, 31, 373
- Perot, Alfred, 53
- Phase change, 28
 in TIR, 30, 34
- Phase condition in lasers, 301
- Phase matching, 487
- Phase matching angle, 487
- Phase mismatch, 475
- Phase modulation, 470
- Phase modulator, 465
 LiNbO₃, 468
- Phase of a wave, 3
- Phase velocity, 5
- Phonon, 197, 375, 495
 energy and momentum, 375
- Phosphors, 249
- Photoconductive detectors, 402
- Photoconductive gain, 402
- Photoconductivity, 404
- Photocurrent, 366, 369, 422
- Photodetection Modes, 367–369
- Photodetector, 365
 neutral region, 366
 quantum efficiency, 375
 Shockley–Ramo theorem, 372
 responsivity, 375
- Photodiode, 365, 383
 circuits, 405–408
 materials, 373
 photocurrent, 370
pn junction, 365
 diagram, 366
 responsivity, 375
 space charge layer (SCL), 366
 spectral responsivity, 375
 table, 373
- Photoelastic effect, 159, 476
- Photogeneration, 366–367

- Photon amplification, 265–266
 Photon cavity lifetime, 300; *see also* Cavity lifetime
 Photon confinement, 319
 Photon flux, 242
 Photon lifetime, *see* Cavity lifetime
 Photonic bandgap, 77, 78
 guided, 162
 Photonic crystal fiber (PCF),
 160–163
 Photonic crystals, 76–82
 Phototransistor, 401
 heterojunction, 402
 Photovoltaic devices, *see* Solar cell
 Photovoltaic mode of operation, 370
 Piezoelectric effect, 482
pin photodiode, 379, 380
 characteristics – table, 389
 junction capacitance, 381
 NEP of a Si, 412
 photocarrier diffusion, 383
 response time, 381
 responsivity, 384
 speed, 383
 steady state photocurrent, 385
 transient photocurrents, 432
 transit time, 381
 Pixel image sensor, 418
 Planck’s radiation distribution law, 271
p-n junction, 198
 band diagram, 318
 graph, 319
 built-in field, 200
 built-in potential, 200, 201
 current density, 210, 132
 depletion region, 199
 diffusion (storage) capacitance, 214
 direct bandgap, 136
 dynamic (incremental) resistance, 213
 energy band diagram, 220
 forward bias, 205, 210
 currents, 206
 diagram, 201
 recombination current, 206
 law of the junction, 202, 204
 metallurgical junction, 198
 properties – graph, 198
 reverse bias, 209, 220
 diagram, 209
 total current, 210
 reverse saturation, 210
 space charge layer (SCL), 199, 211
 Pockels cell modulator, 468
 longitudinal, 465
 transverse, 465
 Pockels coefficients – table, 469
 Pockels effect, 462
 transverse, 465
 Pockels, Friedrich Carl Alwin, 463
 Pockels phase modulator, 465
 Point defect, 81
 Polarization
 angle, 29; *see also* Brewster angle
 anisotropic, 491
 circular, 442
 right, 242
 dispersion, 122
 dispersion effects, 122
 elliptical, 443
 induced, 486
 linear, 443
 modulation, 470
 modulator, 466
 of EM wave, 441, 444
 state, 441
 Polarization transmission matrix, 490
 Population inversion, 265, 272, 312
 threshold, 297
 Poynting vector, 18–22
 Preform, 152
 Pressure broadening, 304
 Prism, 25, 44
 birefringent, 455
 Profile effects–fibers, 122
 Profile index, 137
 optimal, 137
 Propagation constant, 3, 114
 complex, 44
 Propagation vector, 5
 Pseudo photonic bandgap (PBG), 79
 Pulsed Lasers, 307–311
 Pumping, 267, 280
 erbium doped fiber amplifier (EDFA), 280
 gas discharge (collision), 288
 injection, 313
 Pyroelectric detectors, 365
- Q**
- Q*-Switching, 307–309
 Quantum efficiency, 375
 detector, 375
 external differential, 327
 external, 327, 375
 internal, 242, 328
 Quantum noise, 409
 Quantum well, 233
 devices, 233
 GaAs, 323–324
 high intensity LEDs, 233–236
 laser diode, 321
 Quaternary alloy, 237
 Quarter-wave plate retarder, 453
 Quartz, 446, 453
- R**
- Radiant flux, 242
 Radiant sensitivity, 376
 Raman–Nath regime, 477
 Ramo’s theorem, *see* Shockley–Ramo theorem
 Rate equations, laser diodes, 332
 Rayleigh criterion, 63
 Rayleigh range, 8
 Rayleigh scattering, 75
 Rayleigh, John William Strutt, 75
 Rayleigh scattering limit, 146
 Reach-trough voltage, 400
 Real image, holography, 355, 356

- Recombination, 183
 center, 197
 current, 208
 direct, 214
 direct capture coefficient, 215
 indirect, 216
- Recombination lifetime, 214
 definition, 214
 excess minority carrier, 215
 mean, 206
 weak injection, 215
- Reflectance, 32, 55
 bandwidth, 41
 at normal incidence, 32
- Reflection
 amplitude, 26
 at normal incidence, 30, 33
 coefficients, 27
 graph, 31
 external, 30, 36
 at normal incidence, 30
 frustrated total internal, 34, 35
 internal, 30, 36
 graph, 29
 multiple reflections, 70
 and transmission at the Brewster angle, 37
 total internal, 22, 23, 24, 30, 34
- Refracted light, 22
 from a less dense medium, 35
- Refractive index, 11
 complex, 45
 dispersion, 10
 field induced change, 462
 graph vs. wavelength, 11
 nonlinear, 158
 optical crystals, 446
 table, 12
- Resolving power
 angular limit of resolution, 63
 diffraction grating, 66
 imaging systems, 63
- Response time, 381
- Responsivity, 376
 graphs, 377, 382
 table, 389
- Reststrahlen absorption, 46
- Retarding plates, 452
- Return-to-zero (RTZ) data
 rate, 131
- Rise time, 253
- S**
- Saturation drift velocity, 384
- Scattering
 anisotropic, 491
 light, 145, 297
 Rayleigh, 74, 75
- Schottky barrier height, 398
- Schottky-junction photodetector, 397–400
- SCL, *see* Space charge layer, 199
- Second harmonic generation, 485
- Self-phase modulation, 158
- Sellmeier and Cauchy coefficients, 13
- Sellmeier dispersion equation, 13, 83
- Semiconductors, 179–197
 charge neutrality, 199
 compensation doping, 190
 conductivity, 188
 degenerate, 191
 direct bandgap, 194–197, 216
 extrinsic, 187
 III-V compound, 257
 indirect bandgap, 194, 197
 intrinsic, 186
 non-degenerate, 185, 191
n-type, 187
 optical amplifier, 348–349
p-type, 187
 rate equations, 332
 statistics, 184
- Shockley–Ramo theorem, 370, 372
- Shockley equation, 204
- Shot noise, 409
- Shunt resistance, 407
- Side mode suppression ratio, 339
- Silica (SiO_2)
 Germenia ($\text{SiO}_2\text{-GeO}_2$), 85, 153
 refractive index, 16, 85, 153
- Signal to noise ratio (SNR), 286, 410
 of a receiver, 413
- Simpson, J. R., 276
- Single frequency lasers, 338
 cleaved coupled cavity, 340
 distributed Bragg reflection (DBR), 338
 distributed feedback (DFB), 339
- Single-mode fiber, 112
- Single quantum well (SQW), 321
 energy levels, 321
 laser, 321
- Skew ray, 108
- Snell's law, 22–25
- Snell, Willebrord van Roijen, 22
- Solar cell, 421–428
 antireflection coating, 39
 equivalent circuit, 425
 properties – table, 426
- Solar constant, *see* Air-mass
- Soleil–Babinet compensator, 454, 455
- Solid state photomultiplier, 396
- Space charge layer (SCL), 199; *see also* Depletion region
 width and voltage, 212
- Specific rotatory power, 457
- Spectral hole burning, 307
- Spectral intensity, 258

Spectral responsivity, 376
 Spectral width, 56, 57
 of a wave train, 48
 Spontaneous emission, 266
 Spot size, 7
 SQW, *see* Single quantum well (SQW)
 Step-index fibers, 107–116
 Stimulated Brillouin scattering (SBS), 158
 Stimulated emission, 265, 266
 rate, 270
 Stokes shift, 250
 Stop band, 41
 Strong injection, *see* High injection
 Superlattice, 395
 Superposition of waves, 51

T

Tandem solar cell, 427
 Terminal capacitance, 407
 Ternary alloy, 237
 Thermal equilibrium, 271
 Thermal generation, 183
 in SCL, 210
 Thermal velocity, 186
 Thin films
 multiple reflections, 70
 optics, 70, 72–73
 Three-level laser system, 267
 Threshold concentration, 333
 Threshold current, 326, 237, 334
 Threshold wavelength, 372
 Total acceptance angle, 117, 118
 Total internal reflection, 30, 33, 34
 critical angle, 24
 Townes, Charles D., 272
 Transfer distance in coupled waveguides, 474
 Transit time, 381
 Transmission axis, 444
 Transmission coefficient, 26–28
 Transmittance, 32
 at normal incidence, 33
 Transverse electric field (TE), 26
 Transverse magnetic field (TM), 26
 Trench fiber, 150
 Truncated spherical lens, 247
 Turbidity, 76
 Twisted nematic liquid crystal cell, 459
 Tyndall, John, 107

U

Uniaxial crystals, 446
 negative, 446
 optic axis, 446
 positive, 446
 Unpolarized light, 29

V

Valence band (VB), 182
 hole concentration, 186
 Verdet constant, 483
 table, 485
 Vertical cavity surface emitting laser (VCSEL), 344
 Virtual image holography, 354, 355
 Visibility function, 243
 V-number, 100, 102, 104
 V-parameter, 100

W

Waist, beam, 7
 radius, 7
 Wave
 circularly polarized, 442, 453
 diverging, 6
 electromagnetic, 3
 elliptically polarized, 443
 energy density in an EM, 18
 evanescent, 24, 31
 attenuation, 31
 extraordinary, 447
 fields in an EM, 18
 linearly polarized, 29, 109, 276
 monochromatic plane, 3
 ordinary, 447
 plane electromagnetic, 3
 plane-polarized, 441
 sinusoidal, 48
 spherical, 7
 stationary or standing EM, 54

Wave equation, 4, 6

Wavefront, 3
 Gaussian light beam, 8
 Wavefront reconstruction, 356
 Waveguide, 95
 condition, 95–99
 cutoff wavelength, 100
 dielectric, 95–167
 dispersion, 104–107, 125, 171
 coefficient, 121
 diagram, 104
 modes, 101
 mode determination, 102
 multimode, 100
 planar, 104
 propagation constant, 97
 single mode, 100
 symmetric dielectric slab, 95
 diagram, 96
 possible modes, 98
 propagation constant, 98
 transverse propagation, 97
 Wavelength division multiplexing (WDM), 155

- Wave number, 3
Wave packet, 14
Wave vector, 5
 surface, 449
Weakly guiding fiber, 109
Wire grid polarizer, 491
- Wollaston prism, 455, 456, 492
Wood, Robert William, 66
- Y**
Young's two slit experiment, 52

I don't really start until I get my proofs back from the printers. Then I can begin serious writing.

—JOHN MAYNARD KEYNES (1883–1946)¹

¹The *Guardian*, 8 June 1983, p. 22 as cited in A. L. Mackay, *Dictionary of Scientific Quotations*, Institute of Physics Publishing, Bristol, 1991, p. 140.